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CONDUCTIVE STRUCTURES INCLUDING AIRCRAFT ANTENNAE AND ASSOCIATED METHODS OF FORMATION

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims priority to pending U.S. Provisional Application No. 60/440,681, filed January 17, 2003 and incorporated herein in its entirety by reference.

TECHNICAL FIELD

[0002] The present disclosure describes conductive structures, including aircraft antennae, and methods for forming such conductive structures.

BACKGROUND

[0003] Unmanned aircraft or air vehicles (UAVs) provide enhanced and economical access to areas where manned flight operations are unacceptably costly and/or dangerous. For example, unmanned aircraft outfitted with remotely controlled cameras can perform a wide variety of surveillance missions, including spotting schools of fish for the fisheries industry, monitoring weather conditions, providing border patrols for national governments, and providing military surveillance before, during and/or after military operations.

[0004] Unmanned aircraft typically communicate with ground stations via radio frequency transmitters and receivers. Accordingly, conventional unmanned aircraft include both transmitting and receiving antennae. One drawback with some conventional unmanned aircraft antennae is that they may lack adequate power for long-range communication. Another drawback is that some existing antennae may not integrate well with the aircraft aerodynamics. For example, some conventional antennae extend outwardly away from the aircraft fuselage or wing surfaces, increasing the overall drag of the aircraft and the risk of damage to the antennae. Still another drawback is that the connections between the circuitry attached to the antennae and the antennae themselves may in some cases be unreliable or vulnerable to damage. If the antennae or their connections fail, the aircraft can lose communication with the ground station and can accordingly fly in an uncontrolled manner and/or fail to receive and/or transmit data.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] Figure 1 is a partially schematic, front isometric illustration of an aircraft having a plurality of antennae configured in accordance with an embodiment of the invention.

[0006] Figure 2 is a partially exploded, bottom isometric view of a winglet having an antenna assembly installed in accordance with an embodiment of the invention.

[0007] Figure 3 is a partially schematic, top isometric view of a flexible circuit material used to form an antenna in accordance with an embodiment of the invention.

[0008] Figure 4 is a partially schematic, isometric view of a flexible circuit material being rolled to form an antenna assembly in accordance with an embodiment of the invention.

[0009] Figure 5 is a partially schematic, isometric illustration of an antenna assembly formed in accordance with an embodiment of the invention.

[0010] Figure 6 is a partially schematic, isometric illustration of an antenna assembly configured in accordance with another embodiment of the invention.

[0011] Figure 7 is a side elevation view of an embodiment of the antenna assembly shown in Figure 6.

[0012] Figure 8 is a partially schematic, plan view of a flexible circuit material having a substrate and a first conductive layer configured in accordance with an embodiment of the invention.

[0013] Figure 9 is a partially schematic, plan view of the flexible circuit material shown in Figure 8 with second and third conductive layers visible.

[0014] Figures 10A-10B illustrate a method for forming an antenna with a flexible circuit material in accordance with an embodiment of the invention.

[0015] Figure 11 is a partially schematic, cross-sectional view of a portion of the flexible circuit material, taken substantially along line 11-11 of Figure 9.

DETAILED DESCRIPTION

[0016] The present disclosure describes antennae for aircraft, such as unmanned aircraft, and corresponding methods for forming antennae and other conductive structures, such as coaxial conductors. Many specific details of certain embodiments of the invention are set forth in the following description and in Figures 1-11 to provide a thorough understanding of these embodiments. One skilled in the art, however, will understand that the present invention may have additional embodiments, and that the invention may be practiced without several of the details described below.

[0017] Figure 1 is a partially schematic, isometric illustration of an aircraft 100 having antenna assemblies 110 configured in accordance with an embodiment of the invention. In one aspect of this embodiment, the unmanned aircraft 100 can include a fuselage 101, a pair of wings 102 extending outwardly from the fuselage 101, and a propellor 104 positioned at the aft end of the fuselage 101 to propel the aircraft 100 during flight. The aircraft 100 can further include upwardly extending winglets 103, each of which can be connected to one of the wings 102 with fasteners 119, and each of which is positioned to provide the aircraft 100 with lateral stability and control. An antenna assembly 110 can be installed at a forward leading edge 107 of each winglet 103 to provide for communication between the aircraft 100 and other devices, including a control station (not shown). Further details of the formation and installation of the antenna assembly 110 are provided below with reference to Figures 2-11.

[0018] Figure 2 is a partially exploded, partially schematic isometric illustration of one of the winglets 103, configured to house an antennae assembly 110 in accordance with an embodiment of the invention. In one aspect of this embodiment, the winglet 103 includes two opposing winglet surfaces 105 and has a trailing edge 108 facing away from the leading edge 107. In one aspect of this embodiment, the winglet surfaces 105 can be transparent or translucent to allow visual access to the region inside the winglet 103.

[0019] In a further aspect of this embodiment, the winglet 103 can include an opening 106 sized to receive a support member 120. The support member 120 can carry the antenna assembly 110 and corresponding signal transmission and reception equipment. For example, in one embodiment, the antenna assembly 110 can include a plurality of antennas 111 (shown in Figure 2 is a first antenna 111a and a second antenna 111b). In one aspect of this embodiment, the first antenna 111a can include a transmission antenna coupled to a transmitter module 113 with one or more first leads 112a (one is shown in Figure 2 for purposes of illustration). The second antenna 111b can include a receiving antenna coupled to a receiver module 114 with one or more second leads 112b (one is shown in Figure 2 for purposes of illustration). Accordingly, a single antenna assembly 110 can both transmit and receive signals related to the operation of the aircraft 100 (Figure 1) and/or the data collected by the aircraft 100.

[0020] In a further aspect of an embodiment shown in Figure 2, the support member 120 can be configured to releasably carry the antenna components described above. For example, the support member 120 can include a receptacle portion 121 having a transmitter receptacle 123 positioned to releasably receive the transmitter module 113, a receiver receptacle 124 positioned to releasably receive the receiver module 114, and an antenna receptacle 125 positioned to releasably receive the antenna assembly 110. The transmitter module 113, the receiver module 114, and/or the antenna assembly 110 can be removably received in the receptacle portion 121 in a "snap-fit" arrangement. For example, the receptacles 123-125 can be slightly undersized and can be formed from a resilient material (such as a thermally molded plastic) to exert a compressive force on the components they receive. In another embodiment, the receptacles 123-125 can include features (such as projections) that releasably interlock with corresponding features (such as recesses) of the antenna components. In any of these embodiments, the support member 120 can further include a cover portion 122 hingedly coupled to the receptacle portion 121 to protect and further secure the components contained in the receptacle portion 121. In a particular aspect of this embodiment, the cover portion 122 can include locking tabs 126 that are securely and releasably received in lock receptacles 127, also in a snap-fit configuration.

[0021] In one embodiment, the transmitter module 113, the receiver module 114, and the antenna assembly 110 can be releasably positioned in the receptacle portion 121, and the cover 122 can be releasably secured to the receptacle portion 121. The closed support member 120 can then be inserted into the opening 106 of the winglet 103, with the antenna assembly 110 positioned proximate to the leading edge 107 of the winglet 103. When the antenna assembly 110 in this position, the antennas 111 have a forward facing, vertical orientation, which can be particularly suitable for receiving and/or transmitting signals.

[0022] Once the support member 120 is inserted into the winglet 103, the opening 106 of the winglet 103 can be closed with an end cap 109. The end cap 109 can have holes 118 to receive the fasteners 119 described above with reference to Figure 1. The end cap 109 can further include a connector opening 117 sized and positioned to receive a connector (not shown in Figure 2) that couples the circuitry in the winglet 103 to circuitry in other portions of the aircraft 100 (Figure 1). Further details of support member arrangements are described in U.S. Application No. _____________ (attorney docket no. 36761.8011US01), entitled "Method and Apparatus for Supporting Aircraft Components, Including Actuators," filed concurrently herewith and incorporated herein in its entirety by reference.

[0023] Figure 3 is a partially schematic, isometric illustration of a flexible circuit material 130 that can be used to form antenna assemblies (including the antenna assembly 110 described above with reference to Figure 2) in accordance with an embodiment of the invention. In one aspect of this embodiment, the flexible circuit material 130 can include a substrate 131 formed from a flexible, low dielectric constant insulator, such as Kapton® or other polyimides. The flexible circuit material 130 can further include one or more conductive layers 132 (two are shown in Figure 3 as a first conductive layer 132a adjacent to one face of the substrate 131 and a second conductive layer 132b adjacent to the opposite face of the substrate 131). The conductive layers 132 can include a low resistivity conductive material, such as copper, that can be selectively removed from the substrate 131 to form circuit elements, such as leads and/or conductive traces, using generally available techniques.

[0024] Referring now to Figure 4, the flexible circuit material 130 can be processed to form one or more antennae, such as the antennae 111 shown in Figure 2. For example, in one embodiment, the second conductive layer 132b can be removed from the flexible circuit material 130, as can a portion of the substrate 131 indicated in dashed lines in Figure 4. A portion of the remaining first conductive layer 132a can also be removed, such that the remaining conductive material from the first conductive layer 132a forms the first and second leads 112a, 112b. In one embodiment, the conductive material can be processed to form one first lead 112a and one second lead 112b. In other embodiments (such as those described below with reference to Figures 6-11), the conductive material can be processed to form more leads, for example, two first leads 112a and two second leads 112b.

[0025] In any of the foregoing embodiments, additional portions of the first conductive layer 132a (adjacent to the substrate 131) can remain intact. The flexible circuit material 130 can then be rolled or otherwise formed (for example, around a mandrel) into a cylindrical shape, as indicated by arrow A in Figure 4. In one embodiment, the cylinder can have an open side. In other embodiments, the edges of the flexible circuit material 130 can be joined, for example, as described below with reference to Figure 5.

[0026] Referring now to Figure 5, the flexible circuit material 130 can be rolled up through an angle of 180 degrees so that opposing edges 135a, 135b abut each other, forming a closed cylinder 115. The abutting edges 135a, 135b can be joined at a seam 134 so that the flexible circuit material 130 retains a cylindrical shape. In one aspect of this embodiment, the abutting edges of the first conductive layer 132a can be joined at the seam 134 with an electrically conductive bond (for example, using soldering or welding techniques), and the abutting edges of the substrate 131 can be joined at the seam 134 with a non-conductive bond (for example, using a non-conductive epoxy adhesive). In other embodiments, the edges 135a, 135b of the flexible circuit material can be overlapped rather than butted when joined, as described in greater detail below with reference to Figures 10A-10B.

[0027] In another aspect of an embodiment shown in Figure 5, a support material 133 (which can include epoxy or other suitable materials) can be disposed in the interior of the cylinder 115 formed by the flexible circuit material 130. The leads 112a, 112b can be routed out through the cylinder 115 at the seam 134 for connections to signal transmission and/or reception equipment. The resulting antenna assembly 110 can include the first antenna 111a coupled to the first lead 112a, and the second antenna 111b coupled to the second lead 112b. The antenna assembly 110 can then be installed in the winglet 103 (as described above with reference to Figure 2), or in another portion of the aircraft 100 (Figure 1).

[0028] In other embodiments, the antenna assembly 110 can have configurations other than those described above. In still further embodiments, the foregoing techniques can be used to form other conductive structures, such as coaxial conductors. Accordingly, the conductive layers 132a and 132b can remain continuous (as indicated in Figure 5 with solid lines for the first conductive layer 132a and phantom lines for the second conductive layer 132b) and the first and second leads 112a, 112b can be eliminated.

[0029] Figures 6-11 illustrate an antenna assembly 610 (and associated methods for its formation) in accordance with further embodiments of the invention. Referring first to Figure 6, the antenna assembly 610 can include a flexible circuit material 630 having a substrate 631 and formed to include two antennae 611 (shown as a first antenna 611a and a second antenna 611b). In one embodiment, the first antenna 611a can include a transmitter antenna and the second antenna 611b can include a receiver antenna. In a further aspect of this embodiment, each of the antennae can have a 1/4 wavelength dipole configuration. In a particular embodiment, the first antenna 611a can be configured to transmit signals at 2400 MHz and the second antenna 611b can be configured to receive signals of 900 MHz. In other embodiments, the antenna assembly 610 can include more or fewer antennae 611 having similar or different configurations, depending upon the uses intended for the antenna assembly 610.

[0030] In one aspect of an embodiment shown in Figure 6, the flexible circuit material 630 can further include a transmitter portion 640 and a receiver portion 650. The transmitter portion 640 can carry a transmitter and associated circuitry electrically coupled to the first antenna 611a. The receiver portion 650 can carry a receiver and corresponding circuitry electrically coupled to the second antenna 611b. A connector 670 can provide for electrical communication between the transmitter portion 640, the receiver portion 650, and other devices and components of the aircraft 100 described above with reference to Figure 1.

[0031] Figure 7 is a side elevation view of an embodiment of the antenna assembly 610 shown in Figure 6. As shown in Figure 7, the transmitter portion 640 of the flexible circuit material 630 can carry a transmitter module 613 coupled to a transmitter filter 641, both of which are coupled to the first antenna 611a. In a particular aspect of this embodiment, the transmitter module 613 can include an 800 mW video transmitter and the transmitter filter 641 can include a 2400 MHz bandpass filter. In other embodiments, these components can have other configurations. The receiver portion 650 can include a receiver module 614 and a receiver filter 651, both of which are coupled to the second antenna 611b. In a particular aspect of this embodiment, the receiver module 614 can include a 900 MHz modem available from FreeWave of Boulder, Colorado, and the receiver filter 651 can include a 900 MHz bypass filter. In other embodiments, these components can have other configurations. Further details of the interconnections between these components are described below with reference to Figures 8-11.

[0032] Figure 8 is a partially schematic, top plan view of a portion of the flexible circuit material 630, including the substrate 631 and a first conductive layer 632a positioned adjacent to a lower surface of the substrate 631. For purposes of illustration, the substrate 631 is shown as being transparent in Figure 8 so that the first conductive layer 632a is visible. The first conductive layer 632a can be processed, for example, by subtractive etch techniques, to form a first transmitter ground plane 642a and a first receiver ground plane 652a. The first transmitter ground plane 642a can be electrically isolated from the first receiver ground plane 652a by a gap 636. Accordingly, the first transmitter ground plane 642a can provide a ground bus and shielding for components of the transmitter portion 640, and the first receiver ground plane 652a can provide an electrically isolated ground bus and shielding for components of the receiver portion 650.

[0033] The first conductive layer 632a can further include first antenna overlap connectors 637a and second antenna overlap connectors 637b. As described in greater detail below with reference to Figures 10A-10B, the overlap connectors 637a, 637b can provide electrical continuity for the cylindrical, dipole antennas 611a, 611b shown in Figures 6-7.

[0034] Figure 9 is a top plan view of the flexible circuit material 630, illustrating aspects of a second conductive layer 632b positioned adjacent to an upper surface of the substrate 631, and a third conductive layer 632c positioned on top of portions of the second conductive layer 632b. For purposes of illustration, the first conductive layer 632a shown in Figure 8 and positioned on the opposite side of substrate 631 is not shown in Figure 9.

[0035] In one aspect of an embodiment of the flexible circuit material 630 shown in Figure 9, the second conductive layer 632b can include first antenna conductor portions 638a. As described in greater detail below with reference to Figures 10A-10B, the first antenna conductor portions 638a can be formed into a generally cylindrical first antenna. This second conductive layer 632b can further include a transmitter module connection site 644 having conductive terminals positioned to receive corresponding connections from the transmitter module 613 (Figure 7). The second conductive layer 632b can still further include transmitter circuitry 645 which connects the transmitter module connection site 644 with the connector 670, and first antenna leads 643 which connect the transmitter module connection site 644 with the first antenna conductor portions 638a.

[0036] The second conductive layer 632b can also include second antenna conductor portions 638b (which, as described below with reference to Figures 10A-10B can be used to form a generally cylindrical second antenna). The second conductive layer 632b can further include a receiver module connection site 654 having terminals for coupling to the receiver module 614 (Figure 7). The second conductive layer 632b can still further include receiver circuitry 655 that couples the receiver module connection site 654 to the connector 670, and second antenna leads 653 that couple the receiver module connection site 654 to the second antenna conductor portions 638b.

[0037] In further aspects of this embodiment, the transmitter circuitry 645 and/or the receiver circuitry 655 can include other circuit elements, including resistors and/or capacitors 671 (shown as first resistors and/or capacitors 671a and second resisters and/or capacitors 671b). For example, in one aspect of this embodiment, the first resistors and/or capacitors 671a can be used to control the impedance of the connection between the connector 670 and the transmitter module connection site 644 and/or the receiver module connection site 654. In another embodiment, the second resistors and/or capacitors 671b can be used to control the impedance between the module connection sites 644, 654 and the corresponding antenna conductor portions 638a, 638b.

[0038] In still a further aspect of an embodiment shown in Figure 9, the substrate 631 can support the third conductive layer 632c. The third conductive layer 632c can include silver and/or another conductive material disposed on a polyimide or other dielectric material, which is in turn disposed on the exposed portions of the second conductive layer 632b. Accordingly, the third conductive layer 632c can be electrically isolated from the second conductive layer 632b. In yet another aspect of this embodiment, the third conductive layer 632c can be electrically coupled to portions of the first conductive layer 632a described above with reference to Figure 8. For example, the third conductive layer 632c can include a second transmitter ground plane 642b electrically coupled to the first transmitter ground plane 642a (Figure 8) with vias (not visible in Figure 9). The third conductive layer 632c can further include a second receiver ground plane 652b coupled to the first receiver ground plane 652a (Figure 8) with additional vias (also not visible in Figure 9).

[0039] In one embodiment, the third conductive layer 632c can be added to the flexible circuit material 630 by first providing a dielectric material over the second conductive layer 632b. Via openings are then formed through the dielectric material and through the substrate material 631. Accordingly, the via openings can terminate adjacent to the first conductive layer 632a (Figure 8). The third conductive material 632c (which can include a silver-filled conductive epoxy or other suitable materials) can be screened onto the underlying dielectric material to (a) fill the via openings and form corresponding vias and (b) form the second ground planes 642b, 652b. Accordingly, the second ground planes 642b, 652b can be coupled to the first ground planes 642a, 652a, respectively, by the conductive vias extending through the substrate 631.

[0040] One feature of an embodiment of the antenna assembly 610 described above with reference to Figures 6-9 is that the first antenna leads 643 can pass between two spaced apart transmitter ground planes 642a, 642b, and the second antenna leads 653 can pass between two spaced apart receiver ground planes 652a, 652b. One advantage of this feature is that the ground planes positioned on opposite sides of the antenna leads can provide for improved shielding of the antenna leads. Another advantage of this arrangement is that the impedance of one or more of the ground planes can be controlled to reduce and/or eliminate the likelihood for signal reflection at the corresponding antennas, as described in greater detail below with reference to Figure 11. As a result, the strength of the signals transmitted and/or received at the antenna 611a or antenna 611b (Figure 7) can be increased, which can reduce the likelihood for losing communication between the aircraft 100 (Figure 1) and its ground station.

[0041] Figure 10A is a partially schematic, cross-sectional illustration of a portion of the flexible circuit material 630, taken substantially along line 10A-10A of Figure 8. As shown in Figure 10A, the flexible circuit material 630 can include an initially flat portion of the substrate 631, with the first antenna overlap connector 637a positioned on one side, and the first antenna conductor portion 638a positioned on the other. A conductive via 639 provides electrical continuity between the first antenna overlap connector 637a and the first antenna conductive portion 638a.

[0042] To form the first antenna 611a shown in Figure 10B, the flexible circuit material 630 can be rolled until the first antenna overlap connector 637a overlaps and contacts the first antenna conductive portion 638a. With this arrangement, the first antenna 611a can have an electrically continuous, cylindrical dipole arrangement. One advantage of this feature compared, for example, with a flat or planer dipole antenna, is that the cylindrical first antenna 611a can provide for more omnidirectional signal reception and/or transmission.

[0043] Another feature of this arrangement is that the first antenna 611a can be formed integrally with the circuitry to which it is connected (see Figure 9). An advantage of this feature is that it can reduce the likelihood for breaks or other discontinuities between portions of the antenna circuitry.

[0044] Figure 11 is a partially schematic, cross-sectional view of a portion of the antenna assembly 610, taken substantially along line 11-11 of Figure 9. Also shown in Figure 11 is a computer screen shot illustrating the inputs and outputs used by a computer-based calculator to calculate impedance for an arrangement of the antenna assembly 610. Such a calculator is available from a number of public sources, including the web site located at www.ideaconsulting.com, provided by Idea Consulting of Santa Cruz, California.

[0045] As shown in Figure 11, the antenna assembly 610 can include the flexible circuit 630 having the substrate 631 with the first conductive layer 632a positioned adjacent to one surface, and the second conductive layer 632b positioned adjacent to an oppositely facing surface. An intermediate dielectric material 1131 can be disposed adjacent to the second conductive layer 632b, and the third conductive layer 632c can be positioned adjacent the intermediate dielectric layer 1131. The first conductive layer 632a can include the first transmitter ground plane 642a, the second conductive layer 632b can include the first antenna leads 643, and the third conductive layer 632c can include the second transmitter ground plane 642b. The width and thickness of each antenna lead 643 are represented by letters "W" and "T," respectively. Letter "S" represents the spacing between the antenna leads, letter "B" represents the distance between the first transmitter ground plane 642a and the second transmitter ground plane 642b, and letters "Er" indicate the relative dielectric constant of the material between the two transmitter ground planes 642a, 642b.

[0046] The impedance calculator can be used to determine the value or values of the forgoing variables that result in a trace impedance that reduces and/or eliminates the likelihood for signal reflection at the first antenna 611a. For example, in an embodiment shown in Figure 11, W was chosen to be 0.008 inches, T was chosen to be 0.004 inches, S was chosen to be 0.020 inches, B was chosen to be 0.014 inches, and Er was chosen to be 3.5. The resulting impedance of 62.5 ohms is expected to reduce the likelihood for signal reflection for a 1/4 wavelength dipole antenna transmitting at 2400 MHz. Accordingly, the size, shape, composition, and spacing of these elements can provide for passive termination of the antenna connections. In other embodiments, these variables can have other values, depending upon the particular geometry of the antenna assembly 610 and the characteristics of the signals transmitted and/or received with the antenna assembly 610. In any of these embodiments, the impedance can be further tailored by providing appropriate resistors and/or capacitors 671b (Figure 9) at an interface between the first antenna leads 643 and the first antenna 611a.

[0047] From the foregoing, it will be appreciated that specific embodiments of the invention have been described herein for purposes of illustration, but that various modifications may be made without deviating from the spirit and scope of the invention. The invention is not limited except as by the appended claims.